Four Plane Prototype Module Production at Argonne

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with contributions from:
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and thanks to all those who helped build the modules

1 Introduction

This note will document what was planned for the production of the 4 Plane Prototype modules, how things went and what we learned from the experiments first attempt at a large-scale production of full-scale far detector modules.

This note contains all of the information collected on the modules prior to the build. The information collected during the actual build is now in Pete Border's database. The data from the cosmic ray test stand is available on the web at Fermilab. In the appendices can be found all the documents which were distributed to the crew.

The reason this note is so thorough (okay, long) is because a great deal was learned in preparing for the module construction and during the construction. This information should be made available to anyone who will have the honor of helping to build the modules.

Lastly, I'd like to thank everyone who helped in this endeavor. The crew out in Building 366 did a great job of getting things ready. The pre-construction preparations would not have been completed on time, however, if it had not been for the help we received from our colleagues from the University of Chicago and my summer student Michele Thoele. In addition, the construction of the 24 modules in 3.5 weeks would not have been possible were it not for the help from Fermilab, U of M, Cal Tech, Tufts, Harvard, and UT.

1.1 What we did

The original plan was to begin construction with a four-module day. As the preparations continued it was decided that this was more ambition than necessary. It was decided that starting out building 2/day for a couple of days would provide the opportunity to fix major problems which inevitably pop up at the beginning of new projects.

There was neither the space or the equipment to build 4 modules every day as in a real factory, hence the 4 modules every other day plan. This allowed the same size crew to build modules one day and either detail existing modules or get ready for the next module build the next day.

1.2 Goals

The main goal of this effort was to produce the modules needed for the 4 Plane Prototype at Fermilab. However there were many other reasons why this effort needed to be carried out.

Of the other goals, the primary one was to test the hypothesis that 4 modules could actually be produced in a day. As it turns out, the construction of 4 modules in a day is easily achievable, provided that everything is ready to go into the module. As will be discussed in more detail later, it is the pre-construction preparations and the post-construction detailing which has the potential to slow construction.

Other goals for this construction effort included testing the prototype machinery in a full production situation, check the timing estimates for all construction tasks, and testing all of the construction equipment, including storage and curing racks and cutting jigs.

2 The Original Plan

Like many projects, this one started with a plan for how things would get done. By the time things got started and certainly by the time the modules were complete that plan had been updated, delayed and transformed by outside influences and by what we learned as we built the modules.

In order to highlight how much was learned, I'll first start out be describing what we had planned to do and how.

2.1 QC at the extruder

The original plan for quality control at the extruder was to have each extrusion tested in a black box which would have measured the light output of the extrusion at several points along its length.

The idea was to have data on every extrusion before it ever got shipped to Argonne to maximize the amount of information we would have about the strips as they went into the modules. We were going to keep track of all this data using a PC resident database and bar codes.

Even if the testing machine had been ready for the extrusion process, the database and bar coding plan was not far enough along to put it into use. This should be tested at some future extrusion run. Something like this will definitely be needed for the full production.

2.2 QC during module construction

Here again the idea was to use a PC based database and bar codes to track everything the procedures carried out in the process of building a module and to track the materials which were used in the modules. This tracking was to have included extrusions, fiber, optical epoxy, manifold parts, and optical connectors. It also would have included an ID for each person involved at each stage of the building process.

Again, since the bar coding was not ready and there had been no provision made for having a PC ready for such duty in the factory, an alternate plan was used. Everything was recorded by hand and later entered into the database.

2.3 QC after module construction

Each module was to have been mapped using a radioactive source at Argonne before it was shipped to Fermilab. The detailed map was to go into the database with all of the other information about that module. Unfortunately the mapper was not ready to map at the production rate when the module production started. Most modules were shipped to FNAL without ever being mapped.

One quality control operation which should have been done at this stage but which somehow never got considered was checking the modules to be sure they were light tight. This was a major omission for this production and cannot be allowed to occur again.

3 Scintillator Production

The extrusion run at Quick Plastics lasted from June 28, 1999 through July 2, 1999. Argonne engineer Jim Grudzinski was there the entire time to monitor the quality and take notes.

3.1 Raw Materials

The boxes of polystyrene were purged with argon gas for several days prior to the beginning of the extrusion run. Jim also took samples of the polystyrene from each box. These were delivered to Anna Pla at Fermilab for testing. Jim kept track of when a new box of polystyrene was started in the extruder.

3.2 Sampling

Since there was no 'on-line' testing of the extrusions, Jim was told to periodically cut short samples which were shipped back to Argonne for quick testing. These samples were mostly tested at Cal Tech. For the results see Section 3.4.

Each strip was numbered (by hand) and the samples taken had numbers which reflected their position in the extrusion sequence.

3.3 Tracking

Along with keeping track of the polystyrene and numbering the extrusions, Jim tracked several of the extrusion parameters during the run. These included the temperatures at various stages of the extrusion process, the type of reflective cap material being used, and any visible changes he saw in the extrusions.

3.4 Testing

The sample collected during the extrusion process were tested by Brajesh Choudhary at Cal Tech. The results from his tests are listed below.

Sample ID	Light out compared to QP '97
33	0.83-0.86
53	0.97-1.01
105	0.82
137a	0.79-0.84
137b	0.85
147	0.81-0.82
157	0.78-0.79
178	0.77-0.78
190	0.83-0.85
223	0.82-0.84
255	0.92-0.96
294	0.94-0.96
307	1.01-1.04
323	0.97-0.99
339	0.96-0.99
382	0.84-0.88
425	0.77
458	0.74-0.76
466	0.78
480	0.81-0.84

4 WLS Fiber

The fiber used in the modules was delivered directly to Argonne from Kuraray. The shipment arrived in early July and contained both non-S and S35 type fiber. Six kilometers of non-S type fiber and 5.5 km of S35 fiber were delivered.

4.1 Types used

The plan was to use the non-S fiber first and then the use as much S35 as needed. The first modules were actually built with S35 since that is what had been tested first.

4.2 Test results

The fiber was tested my Leon Maulem and Chad Johnson from U of Minn and by Brajesh Choudhary from Cal Tech. They tested the attenuation length of samples and tested all the fiber for cracks and fat spots in the fiber. Results from these tests are available from Brajesh.

5 Module Types and Symmetry

Because there are 2 different plane orientations and 8 modules per plane, the worst case scenario contains 16 different types of modules. Thanks to rotational symmetries there are only six different types of modules and each plane only has 4 different types. This makes the construction and the mounting much easier.

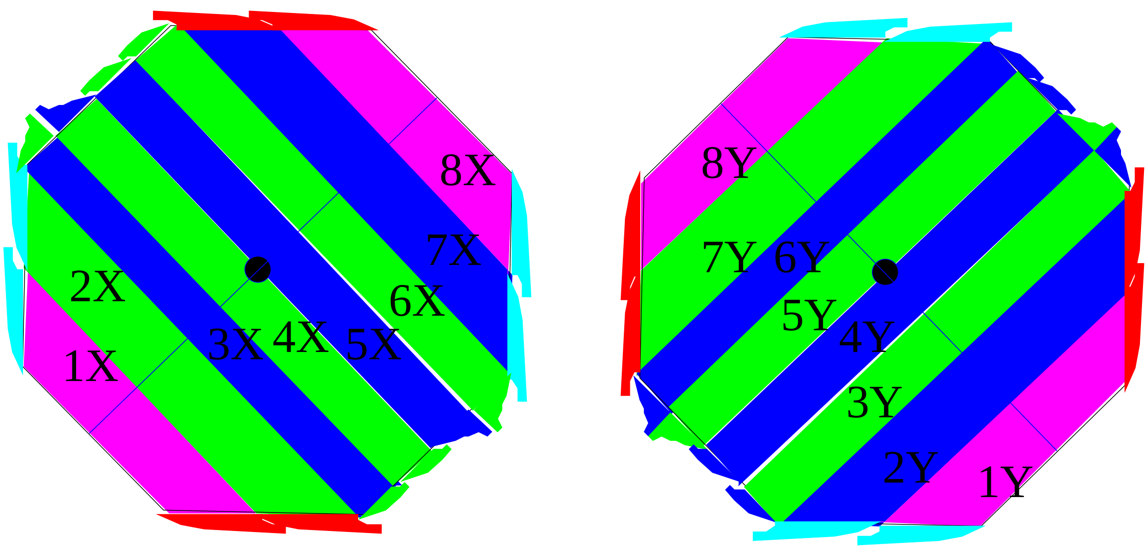
Each plane will contain 2 short 45-degree modules, 2 long 45-degree modules, 2 perpendicular modules and 2 bypass modules. The 45-degree modules are the same for both plane orientations. The bypass and the perpendicular modules have a handedness which depends on the orientation of the modules in the plane. Therefore there are 2 types of each of these.

5.1 Positions of modules in the 2 planes

Plane Positions of Modules

Position	Type
1X	A
2X	B
3X	C
4X	D
5X	D
6X	C
7X	B
8 X	A

Position	Type
1Y	A
2Y	B
3Y	E
4Y	F
5Y	F
6Y	E
7Y	B
8Y	A



Plane X Plane Y

These planes are laid out as if the observer is looking down on the modules mounted on the steal standing at what will become the bottom of the plane when it is hung on the supports. In this view Plane X is a v-oriented plane and Plane Y is a u-oriented plane.

With the different fiber manifolds drawn, one can see the different symmetries which reduce the number of different module types from 16 to 6, but it does not reduce to 4.

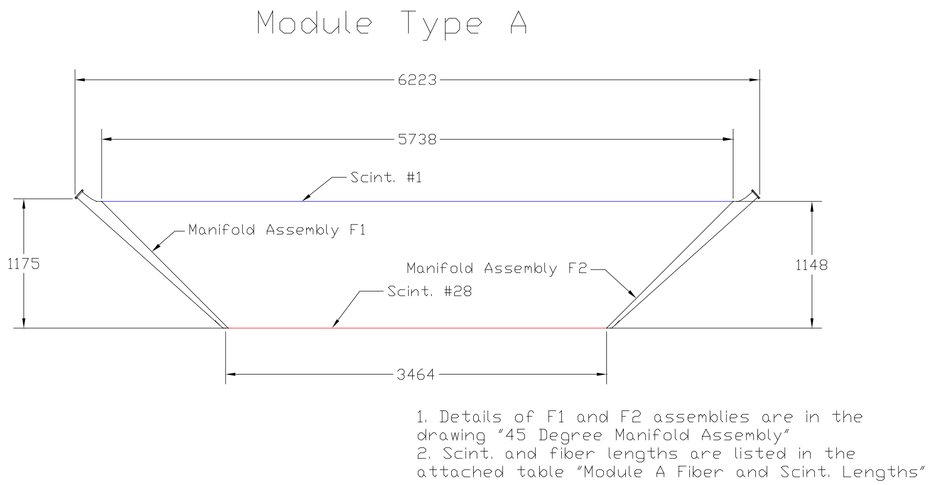
5.2 The 6 Module Types

In order to cut down on the confusion the different types of module have each been given a letter name. The short 45 is type A; the long 45 is type B. Each plane will have two each of these types regardless of the plane orientation.

A plane with the v orientation will have 2 perpendicular modules of type C and two bypass modules of type D. The u orientation will have two perpendicular modules of type E and two bypass modules of type F.

For each module type a drawing of the module is included. Also included are the nominal strip lengths with the length of the fiber tails for each end and the total length of the strip-fiber assembly. The fiber length includes 1 cm extra length for getting the fiber through the connector. All lengths are in millimeters. For the strips in the bypass region the length of the bypass fiber will also be listed.

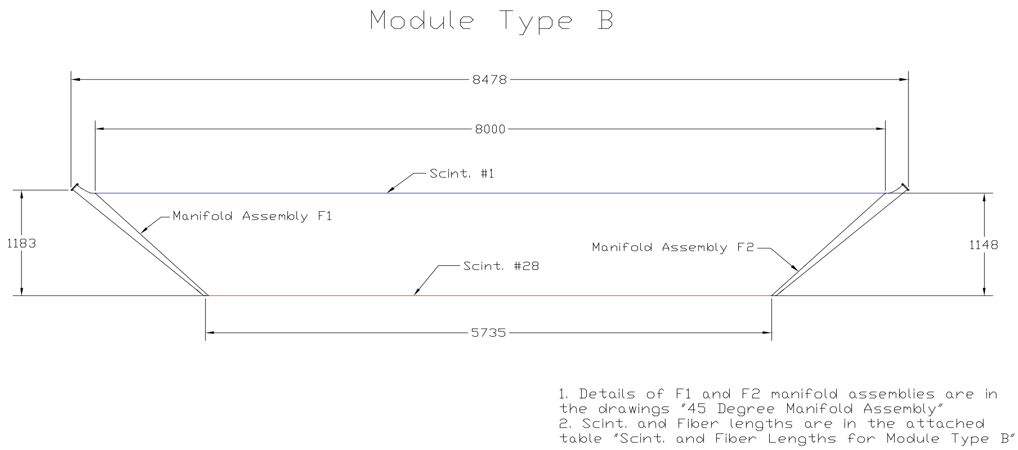
5.2.1 Type A



strip #	scint leng	f1	f2	total
1	5729	286	286	6301
2	5648	345	345	6338
3	5567	403	403	6373
4	5486	461	461	6408
5	5405	519	519	6443
6	5324	578	578	6480
7	5243	636	636	6515
8	5162	694	694	6550
9	5081	752	752	6585
10	5000	811	811	6622
11	4919	869	869	6657
12	4838	927	927	6692
13	4757	986	986	6729
14	4676	1044	1044	6764
15	4595	1102	1102	6799
16	4514	1161	1161	6836
17	4433	1219	1219	6871
18	4352	1277	1277	6906
19	4271	1335	1335	6941
20	4190	1394	1394	6978
21	4109	1452	1452	7013
22	4028	1510	1510	7048
23	3947	1568	1568	7083
24	3866	1627	1627	7120
25	3785	1685	1685	7155
26	3704	1743	1743	7190
27	3623	1802	1802	7227
28	3542	1860	1860	7262

The total amount of fiber needed for this module type is 189.9 m.

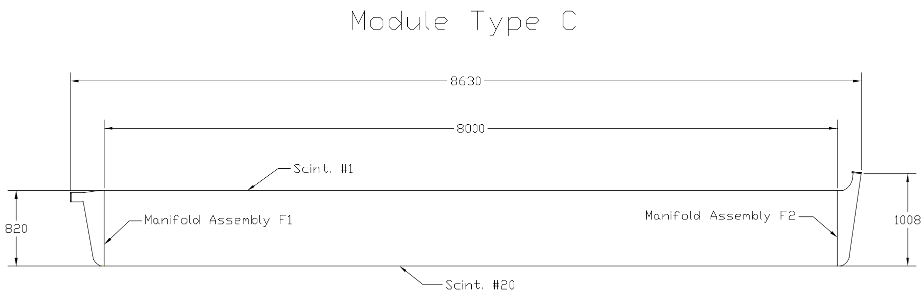
5.2.2 Type B



strip #	scint leng	f1	f2	total
1	8000	286	286	8572
2	7920	345	345	8610
3	7840	403	403	8646
4	7760	461	461	8682
5	7680	519	519	8718
6	7600	578	578	8756
7	7520	636	636	8792
8	7440	694	694	8828
9	7360	752	752	8864
10	7280	811	811	8902
11	7200	869	869	8938
12	7120	927	927	8974
13	7040	986	986	9012
14	6960	1044	1044	9048
15	6880	1102	1102	9084
16	6800	1161	1161	9122
17	6720	1219	1219	9158
18	6640	1277	1277	9194
19	6560	1335	1335	9230
20	6480	1394	1394	9268
21	6400	1452	1452	9304
22	6320	1510	1510	9340
23	6240	1568	1568	9376
24	6160	1627	1627	9414
25	6080	1685	1685	9450
26	6000	1743	1743	9486
27	5920	1802	1802	9524
28	5840	1860	1860	9560

The total amount of fiber needed for this type module is 253.9 m.

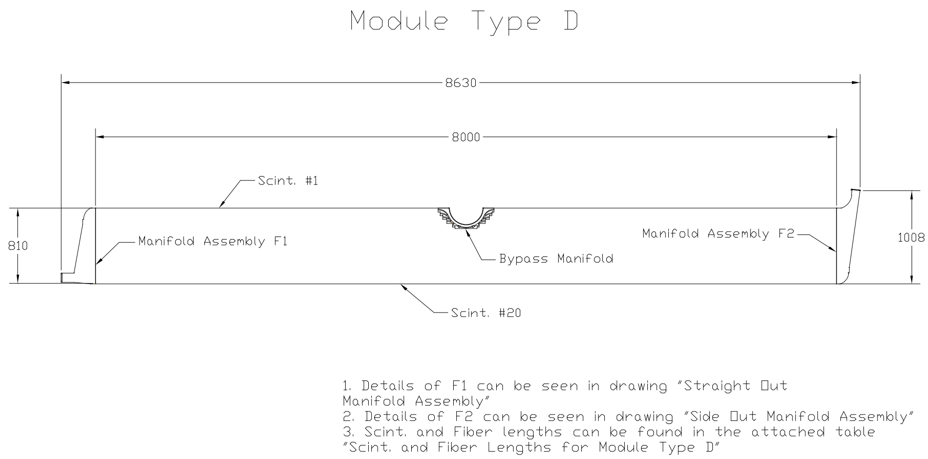
5.2.3 Type C



strip #	scint leng	f1	f2	total
1	8000	389	343	8732
2	8000	389	383	8772
3	8000	396	423	8819
4	8000	409	463	8872
5	8000	429	503	8932
6	8000	454	543	8997
7	8000	484	583	9067
8	8000	518	623	9141
9	8000	555	663	9218
10	8000	592	703	9295
11	8000	628	744	9372
12	8000	666	784	9450
13	8000	703	824	9527
14	8000	740	864	9604
15	8000	777	904	9681
16	8000	814	944	9758
17	8000	851	984	9835
18	8000	888	1024	9912
19	8000	925	1064	9989
20	8000	962	1104	10066

The total amount of fiber needed for this module is 187.0 m. If it was decided to simple make the strips symmetric and then cut off the extra fiber after construction the total length needed is 189 m.

5.2.4 Type D

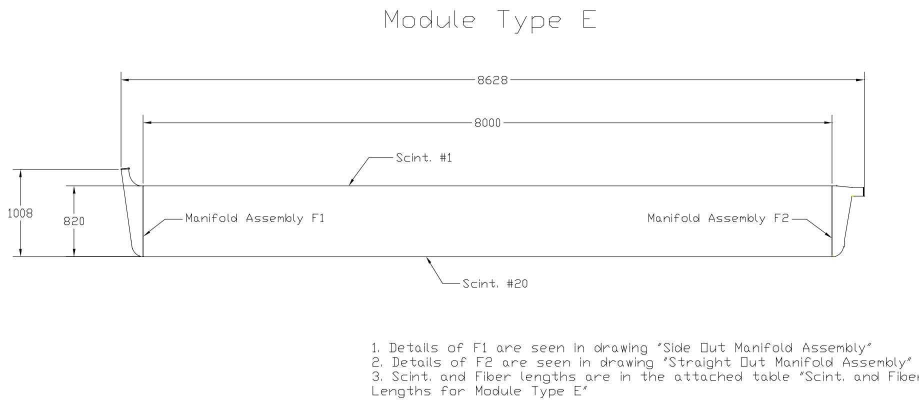


strip #	f1	scint 1	bypass	scint 2	F2	total
1	962	3698	755	3698	343	9456
2	925	3719	665	3719	383	9411
3	888	3749	566	3749	423	9375
4	851	3791	449	3791	463	9345
5	814	3856	295	3856	503	9324
6	777	8000	0	0	543	9320
7	740	8000	0	0	583	9323
8	703	8000	0	0	623	9326
9	666	8000	0	0	663	9329
10	628	8000	0	0	703	9331
11	592	8000	0	0	744	9336
12	555	8000	0	0	784	9339
13	518	8000	0	0	824	9342
14	484	8000	0	0	864	9348
15	454	8000	0	0	904	9358
16	429	8000	0	0	944	9373
17	409	8000	0	0	984	9393
18	396	8000	0	0	1024	9420
19	389	8000	0	0	1064	9453
20	389	8000	0	0	1104	9493

The total amount of fiber needed for this module type is 187.4 m. If the decision is made to make the tails symmetric until after construction the total fiber needed is 194.9 m.

Strip 6 in this module must have a notch cut on the side next to strip 5. The notch is 242 mm long centered on the length (starting 3879 mm from an end) and the width is 19.6 mm, coming very close to the fiber groove.

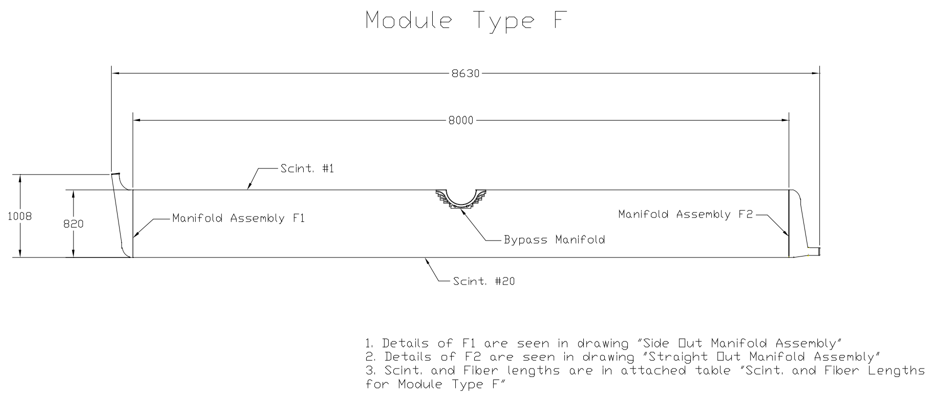
5.2.5 Type E



strip #	scint leng	f1	f2	total
1	8000	343	389	8732
2	8000	383	389	8772
3	8000	423	396	8819
4	8000	463	409	8872
5	8000	503	429	8932
6	8000	543	454	8997
7	8000	583	484	9067
8	8000	623	518	9141
9	8000	663	555	9218
10	8000	703	592	9295
11	8000	744	628	9372
12	8000	784	666	9450
13	8000	824	703	9527
14	8000	864	740	9604
15	8000	904	777	9681
16	8000	944	814	9758
17	8000	984	851	9835
18	8000	1024	888	9912
19	8000	1064	925	9989
20	8000	1104	962	10066

The total amount of fiber needed for this module is 187.0 m. If it was decided to simple make the strips symmetric and then cut off the extra fiber after construction the total length needed is 189 m.

5.2.6 Type F



strip #	f1	scint 1	bypass	scint 2	f2	total
1	343	3698	755	3698	962	9456
2	383	3719	665	3719	925	9411
3	423	3749	566	3749	888	9375
4	463	3791	449	3791	851	9345
5	503	3856	295	3856	814	9324
6	543	8000	0	0	777	9320
7	583	8000	0	0	740	9323
8	623	8000	0	0	703	9326
9	663	8000	0	0	666	9329
10	703	8000	0	0	628	9331
11	744	8000	0	0	592	9336
12	784	8000	0	0	555	9339
13	824	8000	0	0	518	9342
14	864	8000	0	0	484	9348
15	904	8000	0	0	454	9358
16	944	8000	0	0	429	9373
17	984	8000	0	0	409	9393
18	1024	8000	0	0	396	9420
19	1064	8000	0	0	389	9453
20	1104	8000	0	0	389	9493

The total amount of fiber needed for this module type is 187.4 m. If the decision is made to make the tails symmetric until after construction the total fiber needed is 194.9 m.

Strip 6 in this module must have a notch cut on the side next to strip 5. The notch is 242 mm long centered on the length (starting 3879 mm from an end) and the width is 19.6 mm, coming very close to the fiber groove.

5.3 Conventions

Since the plan is to know where everything is in the module after it is all sealed, several conventions need to be established in order to be sure that there is no confusion.

The first convention has already been discussed and that is the naming of the different module types. Each module has 20 or 28 strips, two different manifold, and fibers coming out of 20 or 28 holes in optical connectors at each end. Confusion anywhere along the way could lead to data that is probably undecipherable.

5.3.1 Strip number

For module types A-C and E strip 1 is the strip on the side of the manifold snouts. This strip is always put in the module first. In the case of the 45-degree modules this also corresponds to the longest strip in the module.

For the bypass modules (types D and F) strip 1 is the outside strip in the bypass region. It was decided that the position of the bypass should not be allowed to float and therefore the first strip into the module is the one with the longest bypass fiber.

The strips positions are then numbered consecutively to 20 for the perpendicular modules (type C and E) and the bypass modules (type D and F). The strip positions in the 45-degree modules go from 1 to 28.

5.3.2 Fiber ends

When looking down at a module as it is being constructed with strip 1 farthest away from you, the fiber tails on the left are the F1 fibers and the fibers on the right are the F2 fibers. The manifolds are labeled with this on the outside of the modules. This is important not just for knowing the fiber lengths needed to build the module but it also determines where each fiber comes out in the connector, and therefore which cable connects to it.

5.3.3 Fiber position in connector

The manifolds determine which holes in an optical connector the fibers will be threaded into. Since there are 6 types of modules with 2 manifolds it is important to know which strip is connected to which hole on both the F1 and the F2 ends.

Looking at the connector as it is mounted in a manifold the positions are simply numbered from 1 to 30 from left to right. For each type of module, the strip number and which hole the fiber comes out in each manifold is listed below.

5.3.3.1 Type A

Strip	Fiber position in F1	Fiber position in F2
1	1	30
2	2	29
3	3	28
4	4	27
5	5	26
6	6	25
7	7	24
8	8	23
9	9	22
10	10	21
11	11	20
12	12	19
13	13	18
14	14	17
15	15	16
16	16	15
17	17	14
18	18	13
19	19	12
20	20	11
21	21	10
22	22	9
23	23	8
24	24	7
25	25	6
26	26	5
27	27	4
28	28	3

5.3.3.2 Type B

The fiber routing for type B is the same as for type A.

5.3.3.3 Type C

Strip	Fiber position in F1	Fiber position in F2
1	1	30
2	2	29
3	3	28
4	4	27
5	5	26
6	6	25
7	7	24
8	8	23
9	9	22
10	10	21
11	11	20
12	12	19
13	13	18
14	14	17
15	15	16
16	16	15
17	17	14
18	18	13
19	19	12
20	20	11

5.3.3.4 Type D

Strip	Fiber position in F1	Fiber position in F2
1	11	30
2	12	29
3	13	28
4	14	27
5	15	26
6	16	25
7	17	24
8	18	23
9	19	22
10	20	21
11	21	20
12	22	19
13	23	18
14	24	17
15	25	16
16	26	15
17	27	14
18	28	13
19	29	12
20	30	11

5.3.3.5 Type E

Strip	Fiber position in F1	Fiber position in F2
1	1	30
2	2	29
3	3	28
4	4	27
5	5	26
6	6	25
7	7	24
8	8	23
9	9	22
10	10	21
11	11	20
12	12	19
13	13	18
14	14	17
15	15	16
16	16	15
17	17	14
18	18	13
19	19	12
20	20	11

5.3.3.6 Type F

Strip	Fiber position in F1	Fiber position in F2
1	1	20
2	2	19
3	3	18
4	4	17
5	5	16
6	6	15
7	7	14
8	8	13
9	9	12
10	10	11
11	11	10
12	12	9
13	13	8
14	14	7
15	15	6
16	16	5
17	17	4
18	18	3
19	19	2
20	20	1

6 Schedule

July 8-11: Brajesh testing fibers
July 8-11: Leon (and friends) testing fibers

	July 14	July 15	July 16	July 19	July 20	July 21	July 22	July 23
Day type	Constr.	Constr.	Inspect	Constr.	Inspect	Constr.	Inspect	OFF
Crew Chief	Ken	Ken	Ken	Ken	Ken	Ken	Ken	You can go to the scint meeting at FNAL instead!
Phys. in charge	Tacy	Tacy	Tacy	Tacy	Tacy	Tacy	Tacy	
ANL 1	Frank	Frank	Frank	Frank	Frank	Frank	Frank	
ANL 2	TBA	TBA	TBA	TBA	TBA	TBA	TBA	
Cal Tech	Hanson	Hanson	Hanson	Hanson	Hanson	Hanson	Hanson	
Minn.	Nathaniel	Nathaniel	Nathaniel	Nathaniel	Nathaniel	Nathaniel	Nathaniel	
FNAL	Robin	Robin	Donna	Donna	Donna	Robin	Robin	
Phys. Tech	JC	JC	JC	Brajesh	Rich	Rich	Brajesh	
Phys. Tech	S. Eilerts	S. Eilerts	S. Eilerts	R. Lee	R. Lee	R. Lee	R. Lee	
Module types		*A,B*	*C*	*D*		*A-D*		

	July 26	July 27	July 28	July 29	July 30	Aug 2	Aug 3	Aug 4
Day type	Constr.	Inspect	Constr.	Inspect	Constr.	Inspect	Constr.	Inspect.
Crew Chief	Ken	Ken	Ken	Ken	Ken	Ken	Ken	Ken
Phys. in charge	Tacy	Tacy	Tacy	Tacy	Tacy	Tacy	Tacy	Tacy
ANL 1	Frank	Frank	Frank	Frank	Frank	Frank	Frank	Frank
ANL 2	TBA	TBA	TBA	TBA	TBA	TBA	TBA	TBA
Cal Tech	(Talaga)	Larry	Larry	Larry	Larry	-	Jason	Jason
Minn.	(Goodman) Nathaniel	Nathaniel	Nathaniel	Nathaniel	Nathaniel	Nathaniel	Nathaniel	-
FNAL	Robin	Robin	Robin	Robin	Donna	Donna	Donna	Robin
Phys. Tech	Patzak	Patzak	Patzak	Patzak	Hwi	Hwi	Dave B.	Dave B.
Phys. Tech	Nelson	Bruce	Bruce	Bruce	Bruce	Nelson		
Module types	*A,B,E,F*		*A,B,E,F*		A-D		A,B,D	C

	Aug 5	Aug 6
Day type	Inspect	Inspect.
Crew Chief	Ken	Ken
Phys. in charge	Tacy	Tacy
ANL 1	Frank	Frank
ANL 2	TBA	TBA
Cal Tech	Jason	Jason
Minn.		
FNAL		
Phys. Tech		
Phys. Tech		
Module types		

7 Brief description of Module Production

This section will give a very brief description of the steps required to build a MINOS module. There will be almost no detail here but you will get an idea of what the general steps are. For a lot of detail you can read Sections 8 through 11. For a quick outline of all of the steps see Appendix A:.

7.1 Cutting

The extrusions were carried from the shipping containers by 2 to 3 people and placed on the cutting table. This table had fixturing for cutting both the 8-meter strips and the diagonal strips. Each extrusion used for the diagonal strips was 11.6 m long enabling the cutter to get a strip for the long 45 and a strip for the short 45 from each extrusion.

After the strips were cut, the ends were de-burred and the end of the groove was beveled to protect the fiber during the gluing process. The strips were also wiped clean before they were placed into the curing channels.

7.2 Gluing

Each curing channel was pulled from the curing rack and placed on the glue machine. The fiber was secured at the end of the dummy scintillator and the tape was placed over it. The glue machine was then started and the glue, fiber and tape were applied to the strip.

Various types of roller were used to push the fiber down into the groove. Some of these rollers were hand rollers while others were attached to the gluing machine.

7.3 Construction

On construction days, 5 people were scheduled to build the modules. Three of these moved the strips from the curing rack to the module and placed them in the module. The other two were fiber routers. One was stationed at each end of the module.

As the strips were removed from the curing channels the routers were in charge of protecting the fibers during the transfer. After a strip was placed into the module the router would route the fiber through the channel in the manifold and thread it through the connector.

Strips could be placed into the module faster than the fiber routers could route the fibers. This is not a problem since once all of the strips are in the module structural epoxy must be spread over the tops of the strips. While this is being done the routers have time to catch up.

7.4 Detailing

The detailing of a module includes potting and fly-cutting the connector, applying the VWS and LIMa, and sealing seams for light leaks. At this time the fiducial marks are put on the module and H-clips are applied.

8 Cutting Procedure

The first step in the cutting procedure was transporting the extrusions from the shipping/storage tubes to the cutting table. This was achieved by having at least 2 and often 3 people carry the strips by hand to the cutting table. Two people could handle the extrusions for the perpendicular modules, but the extrusions for the 45's were over 11 meters long and required 3 people to transport them due to their lack of rigidity.

8.1 45 Degree Modules

- Align rough cut extrusions to fixed 45-degree stop.

- Press extrusions together and slide to reference edge of table (strip 1).
- Clamp at end with stop.
- Record extrusion ID versus position on tracking sheet.
- Cut extrusions at clamped end using the clamp as a guide.
- Remove the clamp and realign cut edge to 45-degree stop.
- Press extrusions together and slide to reference edge of table.
- Clamp edge opposite fixed stop using long 45-degree fixture.
- Cut strips.
- Remove clamp.
- Measure combined width of 28 strips at 1 m intervals, average and record on tracking sheet.
- Transfer extrusion numbers to cut-offs.
- Transport cut strips (module type B) to curing trays.
- Slide cut off pieces to 45-degree stop.
- Reverse order of extrusions and turn them face down (position 1 to position 28, and groove side down, etc).
- Align extrusions to 45-degree stop and reference edge.
- Clamp at opposite end using fixturing for short 45-degree module.
- Cut strips.
- Remove clamp.
- Measure combined width at 1 m intervals, average and note on tracking sheet.
- Flip strips over and transport to curing trays (module type A).

8.2 Perpendicular Modules

For the perpendicular modules, most of the strips were cut in a similar fashion to the 45-degree strips with 2 exceptions. First, only one strip was cut from each extrusions. Second, strips in the region of the bypass were cut by hand.

8.2.1 Most 8 meter strips

- Align rough cut extrusions to fixed 90-degree stop.
- Press extrusions together and slide toward reference edge of table (strip 1).
- Clamp at end stop.
- Record extrusion ID versus position on module tracking sheet.
- Cut extrusions at clamped end using the clamp as a guide.
- Remove clamp and realign cut edges to the stop.
- Press extrusions together and slide toward reference edge of table (strip 1).
- Clamp end opposite fixed stop using the 8 m 90 degree fixture.
- Cut strips.
- Remove clamp.
- Measure combined width of strips at 1 m intervals, average and record on tracking sheet.
- Transport strips to curing trays.

8.2.2 Bypass strips

The bypass strips were sometimes cut to length along with the other strips for the D (F) type module. They were not loaded into the curing channels when the others were. Strips 1-5 were cut into two pieces of the length prescribed by the module design and strip 6 had the appropriate notch cut into it. These cuts were done by hand on each individual strip since the gaps are different lengths for each of the strips.

8.3 Tracking/Quality Control

The plan was to track each extrusion through the entire process and to know exactly where it was in the module. To this end as the strips were cut their location in the module was determined and tracked on the module tracking sheets.

For 45-degree modules this is fairly straightforward. Once a strip is cut its position is set since it must go between its neighbors in order to fit in the module. Once the order of the strips is noted for say the A type module being cut, the order for the B type is set. It is simply the reverse. This fact was used to reconstruct the strips used in a module where the extrusion numbers were not noted on the tracking form.

The 8 meter strips were marked on the cutting table as to which curing channel they were to go in, and this ordering was written down on the module tracking form.

Unfortunately, a couple of modules got cut without all of this information being noted on the tracking form. It is hoped that by automating the tracking process this will not be a problem.

8.4 De-burring and Beveling

It was noticed early in the gluing process that the condition of the end of the groove was important to the safety of the fiber tail. In order to keep the gluing going as fast as possible it was decided that the extrusion cutting table was the best place to inspect the groove and make sure there was nothing at the end which could damage the fiber.

To this end, files were used to clear any burrs left from the actual cutting of the strips from the groove area. The ends of the grooves were also widened and deepened so that the fiber tracking from the dummy scintillator into the strip was easier and less likely to kink the fiber. All of this was done before the strips left the cutting table.

8.5 Cleaning

After the cutting and beveling the tops of the strips were wiped down with isopropyl alcohol to remove plastic chips, sawdust, or any other debris that might have collected in the groove.

8.6 Loading Curing Trays

Once the strips were cut they were loaded into the curing channels, if they were available for that module. If not they were stacked in order at the bottom of the curing rack and covered with plastic to keep them clean. Once the channels were available the strips were slid into the appropriate channel.

8.7 Recommendations

Most of what was learned at this stage had to do with materials movement. The main problem was that the extrusions are extremely floppy at these lengths, which makes them difficult to handle.

8.7.1 Station Position relative to Extrusion Storage

The cutting station should be located close enough to the extrusion storage area that the extrusions can be pulled from their storage container directly onto the cutting table. If this is not possible, the extrusions should be unloaded onto a cart which can be moved to the cutting table with several modules worth of extrusions on it.

8.7.2 Station position relative to curing rack

First, there should be enough curing racks with curing trays that there can be one at the cutting table, one at the glue machine and one near where the modules are being constructed. This is to ensure that all jobs can be done as efficiently as possible.

Second, the curing rack at the cutting table should be positioned in such a way as to make it easy for the cutter to load the strips into the trays as soon as they are ready.

8.7.3 Fixturing for 45 degree cuts

The fixturing for cutting the 45-degree strips should be redesigned so that the extrusions do not have to be readjusted for each cut.

8.7.4 Tool for de-burring

The deburring and beveling was done by hand because the correct size of Dremmel type bit was not on hand. The speed of this process will be increased dramatically if the correct power tool is available for the job.

8.7.5 Jig for bypass strips

A jig for cutting the gaps in the bypass strips should be designed and installed to make this job easier. A separate jig for cutting the notch in strip 6 would also save time and probably some mistakes.

9 Fiber Gluing

The fibers were glued into most strips using the glue machine. Each curing tray was loaded onto the machine and the fiber glued in and covered with aluminized mylar tape. The channel was then put back into the curing rack and the next channel pulled out and placed on the glue machine.

The gluing itself can be handled by one person, but with the current design it takes two people to unload the channel from the rack to the glue machine and to load it back onto the rack.

9.1 Quality Control

The original plan was to track the Epon and TETA batches used for each strip. Since this did not seem to be an easy task without everything being bar-coded that part was dropped. What was tracked was the fiber batch which went into each strip and who was running the glue machine.

In addition, changes in the method were also tracked, although not as conscientiously as they should have been. Things like the glue flow rate were tracked some, as well as the width of the tape and what type of roller was used to push the fiber to the bottom of the groove.

Since the rolling method was changing almost constantly this was not tracked well. This can also be said about the glue flow rate. Because the two were connected, as the roller was changed the glue flow rate was also changed to ensure there was enough glue in the groove.

The change in the tape width was noted in the first couple of modules in which the change occurred. The change was from 3/8" wide tape to 1/2" wide tape. All subsequent modules use the wider tape.

9.2 Glue Machine

The glue machine is the heart of the module building. It glues the wavelength shifting fiber into the groove of the scintillator strip. Automating this process helps to ensure that the projected module production rate can be attained.

9.2.1 How it works

The glue machine does all of the operations needed to glue a fiber into a strip. The curing trays were outfitted with dummy scintillators which set the length of the fiber tail needed for each strip. The fiber was clamped at the end of the dummy strip and placed in the groove until the glue head was at the end of the strip. At this point the aluminized mylar tape was placed over the fiber and the pressure roller was engaged.

The order of operations for the glue machine are: 1) mix the epoxy in the appropriate ratio, 2) lay a bead of epoxy on the groove, 3) lay the fiber in the groove, 4) stretch the aluminized mylar tape over the groove, 5) press down the tape, 6) force the fiber to the bottom of the groove with a shaped roller which pushes down on the tape.

9.2.2 Modifications and optimization

During the construction the shape and material of the final roller was changed many times in order to get the fiber to the bottom of the groove and ensure that all of the epoxy was not squeezed out in the process. The glue flow rate was also changed to minimize squeeze out and maximize the amount of epoxy in the groove.

Studies on both of these have continued since the module production.

9.3 Hand Gluing

As was mentioned in the cutting section, the 6 strips in the bypass region of module types D and F are treated differently. In the case of the fiber gluing it is because the glue machine was not yet ready to deal with a strip in which no glue is applied in the middle.

Before gluing the strips were placed into their curing channels. Dummy scintillators had been placed in the middle so that the length of free fiber was easily known.

The raw edges of strip 6 where the notch had been cut were covered with aluminized mylar tape. This was in part to restore some of the reflectivity lost by removing the coextrusion. It was also to help keep the epoxy in the groove, since the notch sometime took out part of one wall of the groove.

The epoxy was drawn from the glue machine when convenient or mixed by hand. A glue bead was placed in the strip the full length and the fiber was then laid into the groove. The aluminum tape was then placed over the fiber and everything was pushed down.

By already having the strip loaded into the curing tray the strip could be moved around without too much fear of jeopardizing the middle free fiber.

9.4 Recommendations

9.4.1 Position of curing rack

The curing rack should be positioned such that it is easy for one person to load a curing channel onto the glue machine.

9.4.2 Indexing curing rack

Again to make the loading and unloading of the glue machine easier, the curing rack should index up and down.

9.4.3 Beveling groove

As has already been discussed, the groove in the strip should be beveled so that as the glue machine goes from the dummy strip to the real strip the fiber does not run the risk of being kinked or cracked.

9.4.4 Roller to push down fiber

The studies for the best configuration for the roller are ongoing. The roller does need to be a part of the glue machine and not a separate hand held operation. The design also should be optimized for getting the fiber to the bottom of the groove.

9.4.5 Bypass strip 6 fiber tails

It would probably be a good idea to make the fiber tails for the notched strip the same length. This will make one fiber tail too long, but this strip cannot be turned around if the fiber tails need to be switched (going from a D to an F type) if the notch has been put in the wrong side. All other strips can be turned around, but the notch in strip 6 prevents this quick fix.

9.4.6 Fiber Tail Length

The fiber tail lengths listed were 1 cm longer than needed to reach the connector. Given the inaccuracies of the fiber gluing it is recommended that the fibers be at least an inch longer to ensure that they will be long enough.

9.5 Changes during production

Some things were learned during production which were easy enough to fix that the changes were made as the construction continued. Some of these were to improve the modules, while others were to improve the materials handling.

9.5.1 Roller

The roller was continually modified. The shape and the types of materials used were tuned to ensure that the fiber was pushed to the bottom of the groove and that enough epoxy was left in the groove. These studies are continuing.

9.5.2 Beveling

The early glue machine operators noticed that the transition from the dummy strip to the scintillator strip was a dangerous place for the fiber tail. The quick and easy fix was the bevel the groove to ease this transition.

9.5.3 Curing rack shelves

The original curing rack only had cross beams to support the curing channels. However, the curing channels were long enough that as they were slid into the rack they could sag between cross beams. This meant that someone had to walk along the rack as a channel was being slid in to ensure that the channel did not go under a crossbeam.

Shelves were soon added to the rack to eliminate this problem. This also helped to protect the fiber tails while channels were being loaded into or unloaded from the rack.

10 Module Construction

To save time, the skins for all the modules were precut in the sheet metal shop at ANL. This was not in the original plan but it became obvious that for this production it would be better to do it that way. Part of the problem was that the aluminum for the wide modules had not come in yet. Therefore the skins for those modules were cut from aluminum which was too wide and then the sheet was slit to the correct length.

10.1 Manifold Inspection

All of the parts for the manifold assembly were pulled and inspected prior to the building of the module. The reason for pulling all the pieces at once and making sure they stayed together was to ensure that they were inspected before they were installed.

At this time the aluminized mylar tape was installed in the light injection pockets in the LIMa's and in the manifolds themselves. The installation of the tape in the manifolds did not occur at the beginning of the build due to a supervisory error. See Section 12.3.2 for more details.

Also at this time the double sided tape, or carpet tape, was installed in the pockets of the manifold. This tape helps to keep the fiber tails under control while they are being routed. It also helps keep the fibers in place after the construction is completed.

10.2 The Manifold Cart

At each end of the assembly table is what is called a Manifold Cart. It was stocked with tools and supplies typically needed by those routing the fibers in the manifolds. The full list is contained in Appendix C:. Some of the supplies were also used by the gluers/strip handlers during the construction.

10.3 Bottom Cover

As was mentioned before, the covers were precut for this operation to save time and space.

At the beginning of the construction both the top and bottom covers were laid out and aligned so that the alignment holes could be punched at the same time. Once this was completed the top cover was rolled back up and set aside.

10.3.1 Alignment

Since the alignment holes had just been punched all that really had to be done at this point was put the alignment pins through the holes in the skin and into their pin holes.

Both covers are positioned such that the strip 1 edge of the aluminum is about 1/4" from were the edge of the scintillator will be.

10.3.2 Cleaning

Before the structural epoxy was applied to the bottom cover, most if not all of the covers were cleaned with isopropyl alcohol to remove any oil or grease which would keep the epoxy from adhering to the aluminum.

10.3.3 Gluing

The first 12 modules were built using a 4" pitch for the lines of structural epoxy, DP-190. The glue lines were brought to within about 1/2" of the long sides of the aluminum, close enough to ensure all strips were glued but not so close at to allow a lot of squeeze out.

Later modules were built with a 4" pitch for the meter closest to the manifolds with the rest at an 8" pitch. Some of these were made with diagonal glue lines. A few modules were built with what could best be described as random glue lines, although they were actually more intricate patterns, to see if the ripples seen in the modules could be eliminated.

10.4 Manifold Prep

Before the strips can be assembled on the bottom skin, the bottom manifold covers and the manifolds must be glued in place and the connectors installed.

10.4.1 Covers

The bottom manifold cover is actually placed underneath the bottom skin with a bead of DP-190 on the overlap. This is aligned using the alignment blocks in the fixture. Epoxy is then applied along the edges and in the middle of the bottom cover to ensure that the manifold is securely held in place. The manifold itself is then placed on the bottom cover and the bottom skin again using the alignment blocks to ensure that it is in the proper position.

10.4.2 Connector

At this point a thin bead of epoxy was spread in the pocket of the manifold where the optical connector is held and the connector glued in. Care must be taken to ensure that none of the epoxy gets in the fiber holes or the holes for attaching the cable to the connector. Also, the glue well for potting the fibers must be facing up.

10.5 Strip Placement

Ideally the strip curing rack would have been moved to the end of the module assembly table to minimize the transportation distance. Since this was not possible in the prototype factory each strip was transported individually.

10.5.1 Transportation

Construction started with each strip being carried from the strip curing rack to the module assembly table. It was pointed out by Nathaniel Pearson that 2 strips could be carried at a time saving time and trips without jeopardizing the safety of the strips.

Once the strips were at the table the fibers were freed from the dummy strips. The fiber tails were always taped to the dummy strips in at least one place. They were also often stuck to the dummy strips by epoxy from the fiber gluing. The people assigned the task of routing the fibers in the manifolds were also in charge of protecting the fibers as the strips were placed into the module.

10.5.2 Positioning

Each strip was lifted from the curing channels, with the aid of finger holes in the bottom of the aluminum channel, and placed on top of the glue lines on the bottom skin. They were placed as close as possible to the correct position so as not to disturb the epoxy for the subsequent strips. The strips were gently snugged up to eliminate any obvious gaps.

10.5.3 Fiber Threading

The fibers must be threaded one at a time to ensure they do not get crossed. The fiber routers often kept pace with the rate of the strips being placed in the module. This was not required as they had time to catch up while the top cover is being installed.

Typically what slowed down the routing was fat spots in the fiber not caught by the QC machine and optical epoxy on the fiber which made it too wide to go through the connector. Razor blades were used to cut the end of the fiber at an angle. This usually fixed the problem.

For some reason, some of the connectors seemed to have all of the holes too small for even a clean fiber with out any fat spots. A reamer was kept on hand to ream these holes to the proper size.

10.6 Top Cover

The next step is to put the top skin on the module. This is similar to how the bottom skin is put on.

After the top skin goes on the top manifold cover should be glued on. In this case care should be taken to minimize the amount of DP-190 which is liable to get on the fibers.

10.6.1 Glue

Lines of DP-190 are applied to the strips in the module. These were usually perpendicular to the direction the length of the strips, but some lines were put down at 45 degrees (in 45 degree modules) and others were applied in various random patterns. When 8-inch pitch glue lines were used the first meter of the module next to the manifolds was still given glue lines on a 4 inch pitch to ensure structural integrity.

10.6.2 Cleaning

The top cover was cleaned as it was unrolled onto the module. Isopropyl alcohol was used to remove oils from the inside of the skin. This typically took all 3 of the gluers to perform. One to pour on the alcohol, and two to wipe the aluminum and control the unrolling of the cover.

10.6.3 Alignment

The top cover was aligned with the bottom cover and manifolds using the pins in the alignment holes. The holes were placed in the top cover at the same time the holes were punched in the bottom to ensure that they would match.

10.6.4 Top Manifold Cover

The top manifold cover was positioned using the fixturing blocks. Epoxy was applied to the edges to hold it in place. Care was taken to limit the amount of epoxy which got on the fibers. It became obvious that it is impossible to keep all of the epoxy off the fibers.

10.7 U-channels

The U-channels are used to light tight the long edges of the module. They are strips of aluminum bent into U-shapes with two 90-degree bends.

For 4PP production U-channels the full length of the modules were not available so 2 to 3 pieces were used on each side. These were cut to length to match the length of the skins. The ends of the channels for the 45-degree modules were cut at an angle to match the angle of the skin. Notches were also cut for the alignment pins.

The first few modules did not get a good seal between the skins and the channels. The first change made to fix this was to put epoxy on both the side and the top of the u-channel. This helped but did not completely remove the problem. The u-channels were then bent such that the top and bottom parts were no longer parallel and they fit tightly to the skins.

As it turns out, part of the problem with getting a good seal with the u-channels probably had more to do with the quality of the vacuum achieved in the next step.

10.8 Vacuum Seal

The vacuum seal is the virtual lead used to compress the module as the structural epoxy cures. This is one of the simplest ways to get even compression over the full 8 meter length. It also helps the u-channels form a seal around the edges.

The vacuum is formed by spreading a sheet of poly over the module. The side of the assembly tray has a gasket in it. The poly is pulled down over the gasket and help in place by compression bars which are screwed to the table. Once the compression bars are in place the vacuum is turned on.

Attempts were made to reuse the sheets of poly. However, it was almost impossible to line up the screw holes from the previous use with the screws being used to hold the compression bars for the second use. It was also difficult and time consuming to adequately patch the holes.

10.9 Quality Control

At this stage the tracking sheet was filled out with the names of the crew and who routed which manifold. Any fibers which were broken or were too short to get through the connector were noted. Any other problems with the construction were also noted on the tracking sheet.

10.10 Recommendations

The first recommendation to come out of the module construction is to have an easier way to put on the vacuum seal. Screwing in the compression bars is labor intensive and time consuming.

The U-channels should be long enough to span the full length of the module in one piece. The ends should also be precut at the right angle. One suggestion was to cut these when the skins are cut.

The fiber tails need to be clean of any epoxy from the gluing process. One idea is to have a suction device which will remove any squeeze out at the end of the strip before it can be spread onto the dummy strip.

Fiber breakage is probably inevitable. While it was essentially eliminated by the end of the production it will happen occasionally. If it does not happen right at the end of the strip then it should be possible to splice the fiber. The splice will not be as good as a whole fiber but it will be better than nothing and may be easier than replacing the entire strip. The development of a quick fiber splicer should be investigated.

11 Module Detailing

Building a module is far from complete when the last fiber is routed into the connector. The fibers must be potted, flycut and the glue well light sealed. The variable width seals (VWS's) must be installed. The light injection manifolds (LIMa's) must be installed. All seams must be light sealed. Fiducial markings must be placed on the module and the H-clips must be installed. All of this takes time.

11.1 Fiber Potting

The original plan was to pot the fibers in the connectors with 5-minute epoxy in the morning and flycut them in the afternoon. Tests at Indiana indicated that the 5-minute epoxy did not hold the fibers well enough to prevent damage when flycutting. The recommendation was to use the optical epoxy used to glue the fibers into the grooves. This effectively added a day to the detailing since the optical epoxy needed 24 hours to cure.

11.1.1 When

Most of the connectors were potted several days after the module was built. If the connectors could be reached, some were potted the day after they were built while they were still curing on the assembly trays.

At the end of construction it was decided to try to pot the connectors before the vacuum was applied. There was a concern that the epoxy might spread too much for this to be effective. As it turns out, this was quite successful. This should be implemented in all module construction since the epoxy has such a long cure time.

11.1.2 Light seal

The glue well for the fiber potting is not completely filled with the Epon so that it can be light sealed. After the Epon has cured the glue well was filled with DP-270, a black epoxy, to light seal the glue well.

11.2 Fly Cutting

The connector must be flycut before the LIMa is installed but must wait until the fiber potting is cured. The installation of the LIMa must wait since the flycutter is aligned with the top front flange of the connector to ensure that the cut is parallel to the face of the connector.

The first step is to cut the extra fiber protruding from the connector. This is done with a hot knife. The flycutter is then moved into position and aligned with the top flange of the connector using a parallel. The connector is then cut, taking a couple of passes to ensure a clean cut. After these passes the fibers are inspected to see is the cut is clean. If a fiber shows signs of having a crack close to the surface another pass or two can be taken to try to get past the crack.

11.3 VWS and LIMa

The Variable Width Seal (VWS) is used to complete the light seal on the end of the manifold away from the snout. Since the position of this edge of the module relative to the manifold can change as extrusion widths change this piece must be adjustable. For perpendicular modules this is a two piece clamshell with enough width to cover the tolerance. For the 45-degree modules it is one piece which must be trimmed to fit the space from the top cover of the manifold to the U-channel on the side.

The Light Injection Manifold (LIMa) serves two purposes. It light seals the snout of the manifold and it provided the connection for the light injection system to the module. The pockets in the LIMa must be mirrored for the light injection system to be effective.

11.3.1 Installation

As mentioned above, the VWS for the 45-degree modules must be trimmed to the correct length. One end wedges into the U-channel and the other end should be cut off flush with the manifold covers.

The VWS for the perpendicular modules are two pieces. One piece has a flange which inserts into the U-channel. When glued in place the two pieces completely cover the end of the manifold.

The light injection manifolds fit over the top flange of the optical connector and completely cover the fiber side of the snout.

All of these pieces were epoxied in place. Some were attached using the black epoxy DP-270. It was hoped the DP-270 would light tight the joint as well. The DP-270 is not as strong as other epoxies available so the most of the pieces were attached with DP-125, a faster curing formula of DP-190.

11.3.2 Light Seal

Since the DP-270 and the DP-125 did not produce light tight seals the seams around the various pieces needed to be sealed. Some were covered with aluminum tape; others were covered with black RTV. There was concern among the detailers that the epoxy should be allowed to cure before the RTV was applied. This should be investigated before full module production begins.

11.4 Seams

Use of the U-channels on the sides of the modules meant that there was a top and bottom seam which needed to be light tight. Since the vacuum was not as strong as needed for the early modules, the edge of the U-channel was not always against the skin leaving fairly sharp edges available to snag on their surroundings.

11.4.1 Elimination of Sharp edges

Modules where the U-channel was not tight against the skin, had aluminum tape put over the edges of the U-channel, both on the top and on the bottom. The tape was pressed flat and sealed against the skins with tongue depressors.

11.4.2 Light Seal

The taping done to cover the sharp edges was also a light seal. On modules where the vacuum did work the u-channels were not taped except where two pieces butted up against each other. These had to be taped, as there was no other way to light seal them.

The other seams needing attention were the seams between the skin and the manifold covers. These already had DP-190 in them, but they did need additional sealing. Some were sealed with aluminum tape while others were sealed with black RTV.

11.5 Alignment holes

The alignment holes were a challenge. They may be used to help attach the modules to the steel. If that is the case they can not be completely covered or filled which would be the easiest way to seal them against light leaks. Sealing between the aluminum and the manifold was attempted using RTV. Most of the holes were simply taped over using aluminum tape until the decision is made on whether or not to use them for mounting.

11.6 H-Clips

For details on where and how to attach the H-clips see Appendix H:. The details of how many H-clips and where they were to be attached were worked out by Jeff Nelson. Placement was important so that the clips would not interfere with the devices used to measure the magnetic field.

The method for attaching the clips evolved over time. There were no suggested steps for applying them prior to construction. The final method involved cleaning the inside of the clip with isopropyl then roughening the U-channel with sandpaper and then cleaning it with isopropyl. The H-clip was then gently bent to fit snugly on the U-channel and glued in place with DP-125. Some H-clips were mistakenly attached with DP-270 which is probably not strong enough for this job.

11.7 Fiducials

The main fiducial mark needed on the modules is the position of the survey target. Unfortunately the module mapper was not ready at the time. Instead the center of the width of the module was marked at each end 30 cm from the knee in the manifold or from the top of the VWS. The survey targets themselves were not applied at the module factory. The care needed to protect them was not possible in the shipping at that time.

To mount the modules on the steel, it was thought that a centerline marking the middle of the length would be useful. This was also marked during the detailing process. Since the accuracy needed was on the order of millimeters a tape measure was used.

11.8 Quality Control

Every step in the detailing was supposed to be noted on the module tracking sheets with the date it was done and the name of the person who did it. This did not always happen, in part because not all the steps were listed on the original tracking sheet. The tracking sheet in Appendix B: has the changes needed from what was learned during the construction process.

11.9 Problems

The main problem with detailing the modules was the difficulty in getting under the modules to light seal seams on that side. It was difficult to reach all the areas which needed light tighting, even on the manifolds and awkward to work on them.

11.10 Recommendations

The main recommendation here is for a separate module detailing rack where the underside of the module can be made accessible. This would also move the detailing out of the way of other building processes.

The question of whether one can RTV over uncured epoxy should be investigated to a full procedure with complete timing can be created for the detailing of a module.

12 Final Results

12.1 Broken/Cracked Fibers

There were 11 fiber tails which were tagged as either broken or too short. One of these actually seems to read out just fine. In addition there is on strip which appears to be dead in the cosmic ray test stand data which was not labeled as being bad during construction. The last confirmed broken fiber was in module 4PP-12. In addition there were several fibers which were tagged as possibly being cracked. Some of these may show signs of being cracked while others do not. We did notice that optical epoxy on the fiber tails can look like a crack.

Module 4PP-8 is a bypass module. One of its bypass fibers was too short and had to be cut in order to complete the module. This was noted on the tracking sheet and is clearly seen in the cosmic ray test stand data.

12.2 Light Tighting

Getting the modules light tight before shipping was not successful. Part of that was due to lack of a way to test them for light leaks prior to shipping. Another factor was not having enough time to detail them carefully while we were learning where common light leaks could occur.

12.3 Trends

12.3.1 Color of manifold

Modules 4PP-1 and 4PP-2 had their manifold painted black on the inside. This turned out to be a mistake, as the paint tended to collect in the fiber channels, making the fiber routing difficult. All the other manifolds were left solid white.

12.3.2 Light injection reflector in manifold

All of the light injection manifolds have aluminized mylar tape in the light injection pockets. However, the light injection pockets were not mirrored until module 13. This was simply an oversight on the part of the factory management. Since all but two of those modules had white manifolds (see section 12.3.1) I hope the results are not disastrous.

12.3.3 Width of Al tape

Modules 14, 15, and 17-24 have 1/2" wide aluminized mylar tape covering the fiber. All other modules have the 3/8" wide tape covering the fibers. This change was made to make the tracking of the tape over the groove easier.

12.3.4 Epoxy in U-channels

Beginning with module 4PP-9, structural epoxy was put in the top as well as the side of the U-channel before it was put on the module. This was intended to help seal the edges and to prevent sharp edges popping up.

12.3.5 U-channel shape

The U-channels were still not sealing well, even after increasing the amount of epoxy in them. Beginning with 4PP-17 the U-channels were also bent closed so that the edges fit against the module more snugly. The glue was still put in the top as well as the side of the U-channel.

12.3.6 Glue line spacing

Modules 1-12 have glue lines on a 4" pitch. Modules 13-20 have glue lines on an 8" pitch except near the manifolds where they are a 4" pitch for about the first meter.

12.3.7 Glue line pattern

The last four modules, 21 through 24, have random glue patterns. This was done partly to see of the ripples seen in the 8" pitch modules could be eliminated and due in part because some of the gluers were getting bored.

12.4 Random Details

12.4.1 Glue machine schedule

The glue machine was running every day, gluing 2 modules worth of strips per day.

12.4.2 Glue flow rate experiments

The glue flow rate was studied intensively during the construction and has been studied even more since. For more details on this resolution, contact Jim Grudzinski.

12.4.3 Potting agent

The original plan was to pot the connectors with 5-minute epoxy in the morning and fly-cut them in the afternoon. Tests at Indiana showed that the 5-minute epoxy did not hold the fibers securely enough, even after curing for 5-6 hours. The alternative was to pot the connectors with the optical epoxy being used to install the fibers in the strips and then wait 24 hours before flycutting.

This is what was done. Most modules were potted several days after they were built. The last few modules were actually potted before the vacuum was applied. This had been batted around as a solution but had not been tested. It works fine. The epoxy does not seem to leak out and the fibers are securely held for the flycutting.

12.4.4 H-clip fit

The side of the H-clips which slipped over the U-channels was a little wide which made gluing them on securely difficult. They were easy enough to bend closed slightly by hand and this is what was done on many of the modules.

Since that time many of the H-clips were reattached at FNAL. Contact Misha Ignatenko for more information.

12.4.5 Cover cutting jig

Because getting the lengths and angles correct for the module skins is so important, a jig for doing this might be a good idea. It could include the positions of the alignment holes so they can be punched ahead of time. This jig could also be used to cut the U-channels to length ahead of time making it easier to get the channels for the 45-degree modules cut at the correct angle.

Appendix A: 60 Easy steps to building a MINOS Module

How to Build a MINOS Module in 60 Easy Steps

Inspection day jobs:

(Cutting)

1. Select paperwork for module design
2. Select extrusions
3. Move extrusions to trimming table
4. Transfer extrusion number to both ends of 11.6 meter extrusion.
5. Trim strips and fill out QC info for trimming station
6. Wipe grooves with "Q-tip" or Kay-dry and visually inspect strip for defects. Note defects on QC sheet.
7. Remove burr at ends of strips and bevel groove.
8. Load curing tray
9. Load curing tray into curing rack

(Gluing)

10. Pull curing tray from curing rack
11. Glue fiber into strip and fill out module QC info for glue machine (gluing is also a construction day job)
12. Tape fiber tails to dummy strip with Kapton tape
13. Replace curing tray into curing rack

(Manifold inspection)

14. Inspect manifold parts and fill out manifold QC sheets for 4 different modules; install carpet tape and mirror LIMa cavities.
15. Mirror light injection cavities in manifold.

(Aluminum skin prep)

16. Cut top and bottom light case covers and punch holes for 4 modules. Degrease covers to improve glue adhesion.

Construction day jobs:

17. Spray assembly tray with Teflon.
18. Attach connector to manifold
19. Position bottom manifold covers

20. Put glue in bottom manifold covers
21. Unroll bottom light case
22. Clean light case if not done on previous day
23. Put down glue for manifolds
24. Place manifolds in position
25. Put down bottom glue lines
26. Pull curing tray from rack
27. Untape fiber tails
28. Push strip up with finger holes
29. Place strips and in module.
30. Route fibers
31. Top glue lines
32. Unroll top light case; clean as it is unrolled
33. Glue lines in top manifold covers
34. Place top manifold covers in position
35. Cut U-channels to length
36. Bend U-channels shut slightly
37. Apply epoxy to top and side of U-channels
38. Install u-channels
39. Pot connectors
40. Protect fiber ends
41. Install wedges
42. Mark center line
43. Cover with poly sheet
44. Attach compression bars
45. Turn on vacuum
46. Install bridges
47. Rig on next module tray
48. Fill out QC paperwork
49. Go to 16. (until 4 modules built)

Inspection Day Jobs

50. Remove compression bars
51. Remove poly
52. Fill rest of connector glue well with black epoxy
53. Loosen module
54. Flycut connector and fill out QC info

55. attach VWS and fill out QC info
56. attach LIMa and fill out QC info

57. Light tight module
    - Side seams
    - VWS seams
    - LIMa seams
    - Alignment holes
58. map and fill out QC info
59. Mark fiducials; centerline and survey target positions; fill out QC info
60. attach H-clips and fill out QC info

Appendix B: Tracking Forms

Module Tracking Form

Trim Station:
Date:______________________ Operator1:_____________________________
Operator2:_____________________________

Width Measurements: (every meter)

	First half	Second half
Number of Strips (circle one/column)	10 14	10 14
1		
2		
3		
4		
5		
6		
7		
8		
average		

Calculated module average width:____
Comments:

Trim Station (cont):

Strip Number	Strip ID	Curing Channel ID
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		

Op 1:____________________

Op 2:____________________

Comments:

Fiber Installation:

Strip range				
Fiber batch				
Epon Batch				
TETA Batch				
Date:				
Operator 1:				
Operator 2:				

Comments:

Module Assembly:

Date:________________________________

Assembly Crew:

1	
2	
3	
4	
5	
6	
7	
8	

Fiber router, F1:_________________________________

Fiber router F2:__________________________________

ID Manifold F1:__________________________________

ID Manifold F2:__________________________________

Comments:

Connector Potting:

Date:______________________________Operator:_______________________________

Connector Flycutting:

Date:______________________________Operator:_______________________________

VWS Installation:

Date:______________________________ Operator:____________________________

LIMa Installation:

Date:______________________________ Operator:____________________________

Light Tight Check:

F1:	seams:	Date:________________________	Operator:_____________________
	Connector:	Date:________________________	Operator:_____________________
	Align holes:	Date:________________________	Operator:_____________________
F2:	seams:	Date:________________________	Operator:_____________________
	Connector:	Date:________________________	Operator:_____________________
	Align holes:	Date:________________________	Operator:_____________________
Strip 1 seams:		Date:________________________	Operator:_____________________
Strip 20 (28) seams:		Date:________________________	Operator:_____________________

H clip Installation:

Date:____________________________________ Operator:_____________________________

Mapping:

Date:_________________________ Operator:__________________________

File location:____

Shipping Crate Packing:

Date:_______________________________ Crate ID:___________________________

Operator 1:___________________________ Operator 2:_________________________

Shipping:

Date:________________________________

Destination:______________________________

Appendix C: Manifold cart supply list

Manifold Cart Supply List:

- Razor blades
- Scissors
- Tape
- Isopropyl alcohol
- K-dry’s or Chem-wipe’s
- Tubing for manifold fixturing
- Screws (for compression bars)
- Washers (for compression bars)
- Fiber end supports and covers
- Connector potting supplies
  - 5-minute epoxy
  - DP-270
  - EPX gun (hand held caulk gun)
  - Static mix nozzles
- Cordless drill
- Drill bits
- Spatulas (at least 2)
- Hole punch for light case alignment holes
- Gloves
- Safety glasses
- Vacuum pins and blanks (for module trays)

Appendix D: Fiber QC sheet

Fiber QC Sheet

Parent Reel ID:______________________________
Date Tested:______________________
Testors:____
____
____

Attenuation Length:____

Fault testing results:

Subreel ID:	Amount on Reel:

Appendix E: Manifold QC Steps

Manifold QC Steps

1. Pull all parts
   a) Manifold
   b) Top and bottom covers
   c) VWS (1 or 2 parts)
   d) LIMa
   e) connector
2. Ream fiber holes in connector
3. File plastic around copper inserts on connectors
4. Apply double sided tape in tape wells of manifolds. If the cover is white place an 'x' on it.
5. Label top cover with module ID, type and manifold end
6. Tape together VWS and LIMa. Label with module ID, type and manifold end.
7. Apply Al tape to light injection pockets on manifold.

NOTE: RH refers to the direction of the snout when looking at the cut out side of the manifold with the strip edge towards you - the snout is on the right.

Appendix F: Manifold checklist

Manifold F1: Module Type A,B Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold RH 45 degree			
Inspect LH top cover; 45 degree			
Inspect RH top cover; 45 degree			
Inspect/clean VWS; 45 degree			
Inspect LIMa; RH 45 degree			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F2: Module Type A,B
Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold LH 45 degree			
Inspect LH top cover; 45 degree			
Inspect RH top cover; 45 degree			
Inspect/clean VWS; 45 degree			
Inspect LIMa; LH 45 degree			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F1: Module Type C
Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold RH perpendicular straight			
Inspect LH top cover; Perpendicular Straight			
Inspect RH top cover; perpendicular straight			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; RH perpendicular straight			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F2: Module Type C Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold LH perpendicular side			
Inspect RH top cover; Perpendicular side			
Inspect LH top cover; perpendicular side			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; LH perpendicular side			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F1: Module Type D Checklist

Module ID:___________________________

Job:	**Part ID: (if available)**	**Date:**	**Initialed:**
Inspect/Clean Manifold LH perpendicular straight			
Inspect RH top cover; Perpendicular Straight			
Inspect LH top cover; perpendicular straight			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; LH perpendicular straight			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Bypass

Job:	**Part ID: (if available)**	**Date:**	**Initialed:**
Inspect/Clean Manifold Bypass			
Install double sided tape in bypass			

Manifold F2: Module Type D Checklist

Module ID:___________________________

Job:	**Part ID: (if available)**	**Date:**	**Initialed:**
Inspect/Clean Manifold LH perpendicular side			
Inspect RH top cover; Perpendicular side			
Inspect LH top cover; perpendicular side			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; LH perpendicular side			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F1: Module Type E Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold RH perpendicular side			
Inspect LH top cover; Perpendicular side			
Inspect RH top cover; perpendicular side			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; RH perpendicular side			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F2: Module Type E Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold LH perpendicular straight			
Inspect RH top cover; Perpendicular straight			
Inspect LH top cover; perpendicular straight			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; LH perpendicular straight			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Manifold F1: Module Type F
Checklist

Module ID:___________________________

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold RH perpendicular side			
Inspect LH top cover; Perpendicular side			
Inspect RH top cover; perpendicular side			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; RH perpendicular side			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Bypass

Job:	Part ID: (if available)	Date:	Initialed:
Inspect/Clean Manifold Bypass			
Install double sided tape in bypass			

Manifold F2: Module Type F Checklist

Module ID:___________________________

Job:	**Part ID: (if available)**	**Date:**	**Initialed:**
Inspect/Clean Manifold RH perpendicular straight			
Inspect LH top cover; Perpendicular straight			
Inspect RH top cover; perpendicular straight			
Inspect/clean VWS top; perpendicular			
Inspect/clean VWS bottom; perpendicular			
Inspect LIMa; RH perpendicular straight			
Inspect/clean 30 wide, module connector			
Install Al tape in LIMa			
Install Al tape in manifold			
Install double sided tape in manifold			

Appendix G: Steps for Light Tighting

Steps for Light-Tighting a Module

1. Make sure connectors are potted. If they are not, get them potted and go do something else for a day.
2. Apply DP-270 to glue well in connectors.
3. At each end:
   a) measure down 30 cm from:
      1) break in manifold of 45 degree modules
      2) (not yet determined for perpendicular modules)
   b) Place scribe mark in center of width at that 30 cm distance.
4. Measure length of module. Use a permanent marker to mark a line denoting the center of the length.
5. Tape U-channels with aluminum tape.
6. Fly cut connectors.
7. Glue VWS's on with DP-270. Tape them in place until glue sets.
8. Glue LIMa's on with DP-270. Tape them in place until glue sets.

Appendix H: H-Clip Installation

H-Clip Installation

1. The distances refer to the distance from the center of the length of the module to the edge of the clip closest to the center unless otherwise noted.
2. Distances followed by * are measured from the center unless the far edge of the clip is less than 100 mm from the end of the strips. If that is the case, the clip should be positioned so that the outside edge of the clip is at least 100 mm from the end of the strips.
3. Distance followed by © should be measured from the end of the strip to the outside edge of the clip.
4. The surface of the U-channel should be cleaned and roughened before the clips are installed.
5. Epoxy should be put on the clip and the U-channel to ensure good adhesion.
6. Epoxy drips must be cleaned up so they will not interfere with the mounting of the module on the steel.

Module type A.

H clips on strip 28, side opposite the manifold snouts
± 550 mm
± 150 mm ©

Module Type B:

H clips on strip 28, side opposite the manifold snouts
± 550 mm
± 1300 mm
± 2550 mm *

Module Type C or E:

H clips on strip 20, side opposite the manifold snouts
± 550 mm
± 1300 mm
± 2500 mm
± 3750 mm *

Module Type D or F:

H clips on strip 20, side opposite the bypass manifold
± 550 mm
± 1300 mm
± 2500 mm
± 3750 mm *
One of these per plane has clips in same positions on strip 1.